NASTRAN, NASA'S GENERAL PURPOSE STRUCTURAL ANALYSIS PROGRAM

By

R. L. McComas

NASTRAN is a general purpose digital computer program for the analysis of large complex structures. The acronym NASTRAN is formed from NASA structural analysis. During the annual review of NASA's research program in the area of structural dynamics in January 1964, it became apparent that there was considerable effort by many of the Centers to develop computer programs for structural analysis, designed to meet the particular needs of each of the Centers. It was suggested that perhaps a single program could meet all their needs. The Office of Advanced Research and Technology appointed a committee with representation from eight NASA Centers to study this possiblity. Thus, the Ad Hoc Group on Computer Methods in Structural Analysis was formed.

After 6 months of investigation, the Ad Hoc Group reported to NASA Headquarters that there was no digital program in existence that had broad, uniform capabilities in the three interdependent disciplines of analytical mechanics, numerical methods, and computer programming. The Group did observe that there was considerable capability dispersed throughout the aerospace industry that had not been collected into a single program. They also found that there was a tendency toward proprietary secrecy that inhibited any exchange of information. Communication was further hindered by the lack of compatibility between the structural analysis programs of any two companies. The Ad Hoc Group recommended that NASA sponsor an entirely new program aimed at bringing together all the best structural analysis computer techniques in the state-of-the-art.

NASA Headquarters endorsed the recommendations of the Ad Hoc Group and commissioned them to prepare a set of specifications. Fortunately, the papers from the first Wright Field Conference, "On Matrix Methods in Structural Analysis", were available to consult. The following objectives of the specifications have now been established:

1. Organize the program to be general-purpose.

2. Embody a large three-dimensional structural capability.

3. Establish computer independence.

4. Provide for modification without cascading effects.

5. Build-in the maximum of user convenience.

6. Document all aspects to gain maximum visibility.

The contract to implement the NASTRAN specifications was awarded to Computer Sciences Corporation (CSC) with MacNeal Schwendler, Martin Baltimore, and later Bell Aerosystems Company as subcontractors. The quality of the NASTRAN program and its documentation is testimony to the purposefulness with which the members of the implementation team applied themselves. This team has often exceeded the state-of-the-art guidelines that were established. A few examples are the segment file allocator, the general input/output module, matrix decomposition with active columns, the inclusion of scalar nonlinearities in control of system dynamics, the generality in the plot module, and the development of the self-contained "inverse power with shifts" module for eigenvalue extraction. The overall design of the program has set a new standard for general purpose programs of any discipline. The framework used in NASTRAN can be disassociated from elastic structures and can be applied to other disciplines, because there are no semantic implications in the executive operations. The program abounds in service code, which threads through every step of the problem physics providing convenience to the analyst.

Many policy decisions had to be made as to the content of NASTRAN. The total framework of the program was considered to be the most important; the executive system had to be capable of managing problems unbounded by core, be compact in its space requirements, be able to restart problems, be able to operate efficiently over different computers, and still be maintainable.

It was decided that only basic finite elements would be included to deal with one- and two-dimensional elastic relationships such as beams, plates, and

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axisymmetric shells. Economy of running time for the state-of-the-art elements was the determining factor in their selection. More sophisticated and new elements have appeared in the state-of-the-art since the inception of this program; these can easily be incorporated.

The decision was made to write a single program in Fortran IV with some exceptional areas to be written in assembly language. Fortran IV, version 13, in its various forms on different computers, seems to have stabilized as a language that will be current for a reasonably long time. More than 99 percent of the program is written in Fortran. The program is modular, so that updating is a matter of revamping material within a module without modifying its external appearances.

Hopefully, the framework that has been built has sufficient capability to serve a sizable portion of the large problems that currently exist in the structural analysis community. It is intended that new capability be added or outdated capability be replaced by augmenting or replacing modules. An entire chapter in the Programmer's Manual has been devoted to the topic of Modifications and Additions in anticipation of serving this particular activity. The traffic in the development of new and increasingly versatile elastic modules is expected to be the most active. As analysts increase their use of the program, their detailed needs will become better defined and the result will be that the traffic in "convenience code" will also be expected to increase. It is desired that all such new features be called to the attention of the NASTRAN Project so that these ideas and routines can be disseminated to a broad audience.

A computer program having all of the capabilities of NASTRAN will obviously be large, as NASTRAN is. In fact it is larger than the entire Univac 1108 Exec 8 System Program at the Marshall Space Flight Center Computation Laboratory.

The overall effectiveness of a general purpose program depends in large measure on how well the available programming techniques have been employed in the design of its organizational and control features. NASTRAN has a modular separation of functional capabilities organized under an efficient problem-independent executive system. This approach is absolutely essential for any complex multioperation, multifile application program.

Despite the modular separation, it is clear that modules cannot be completely independent since they are all directed toward solution of the same general problem. In particular they must intercommunicate data between themselves. The executive routine separates system functions from problem solution functions. It establishes and controls the sequence of module execution according to options specified by the user; it establishes and communicates values of parameters for each module; it allocates files for all data blocks generated during program execution and performs input/output to auxiliary files for each module; and it maintains a full restart capability for restoring a program execution after either a scheduled or unscheduled interruption. The executive system is open-ended in the sense that it can accommodate an essentially unlimited number of functional modules, files and parameters.

The functional modules are those modules that perform the actual calculations. They belong to one of four catagories; i. e., structural modules, matrix operations, utility modules, and user modules.

The structural modules are the main subprograms of NASTRAN. Some examples of structural modules, taken from the dynamic analysis, are real eigenvalue analysis, modal dynamic matrix assembler, transient dynamic response, and dynamic data recovery. The NASTRAN development team has made every effort to incorporate the very latest and best structural techniques to perserve accuracy and speed of solution.

Most difficulties in numerical analysis arise in connection with three basic implicit operations; matrix decomposition (or inversion), eigenvalue extraction, and integration of differential equations. The major difficulties that occur in the application of these operations to large problems are excessive computing time, error accumulation, and instability. Many methods that work well with small or moderate size problems are not acceptable for large problems. The method employed for matrix decomposition (triangle decomposition with active column) is especially important because of its extensive use as a base for the other two implicit operations. The method that is employed in the program takes maximum advantage of matrix sparsity and bandedness. The latter aspect is particularly important because of the enormous gain in efficiency that occurs when banding techniques are properly employed by the user in setting up problems for the displacement method.

In general, the solution time for a large structural analysis of any type can be greatly reduced by taking full advantage of the sparsity and bandwidth of the matrices that describe the structural problem.

Other means have been used to improve efficiency for large problems. These include storing sparse matrices in packed form.

The input/output options have been designed to be flexible in order to accommodate the analyst. The plot package is very versatile allowing a choice of orthographic, perspective, or stereoscopic X-Y curve plot. All or portions of the structure can be plotted with varying view, line weight, and color.

The explanation of any complex activity must be subdivided into phases or steps to be intelligible. In the case of a computer program for structural analysis, it is convenient to divide the total effort into a problem formulation phase and a problem solution phase. The beginning of the problem formulation phase occurs in the mind of the analyst. He contemplates, decides what he needs to know, and constructs a mathematical problem whose solution, he hopes, will provide relevant answers to his question. The range of choice in mathematical problem formulation provided by NASTRAN is, however rich in detail, limited to one basic approach; namely, the use of finite element structural models. The idealized structural model in NASTRAN consists of grid points to which loads are applied and at which degrees of freedom are defined. The grid points are connected by elements in the NASTRAN element library. The structural element is a convenient localizing concept for specifying many of the properties of the structure including material properties, mass distribution, and some types of applied loads.

A wide range of elastic elements including several forms of beams, triangular and quadrilateral plates, scalar elements, and special shell and axisymmetric solid elements have been included in the element library.

Anisotropic material properties may be employed in all plate elements. With modeling experience, there is no aerospace structure that cannot be accurately modeled by the NASTRAN elements. Some examples that are currently being solved by NASTRAN are the dished head assembly (Fig. 1) and the ATM solar panels (Fig. 2). The idealized model of the dished head assembly (Fig. 3) is formed by beams and triangular plates. The grid mesh has been increased in the area of interest, the intersection of the two surfaces. Since the assembly is symmetric, only half of the structure needs to be modeled.

Now, all that is left to be done is to fill out the NASTRAN data cards (a simple although sometimes tedious task) and choose the analysis type, of which there are twelve available. There are five rigid

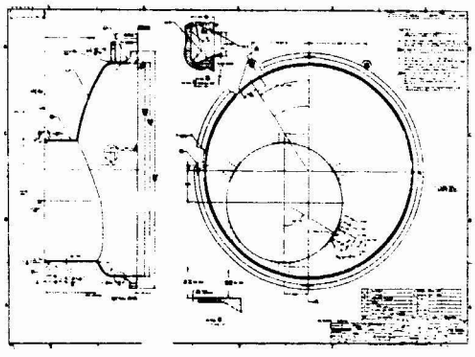

Figure 1. Dished head assembly drawing.

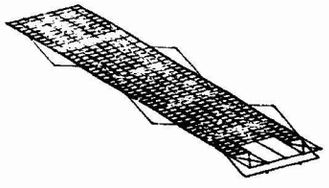

Figure 2. Finite element model of ATM solar array.

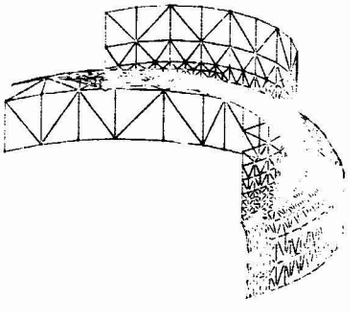

Figure 3. Finite element model of dished head assembly.

formats, as they are called in NASTRAN, for static and seven for dynamic analysis.

In this problem, the stress and deflections were desired. However, it is possible to save the problem solution and to restart and perform a different analysis at a later date, possibly a vibration analysis, without duplicating the original effort.

The documentation for the NASTRAN Computer Program consists of three manuals; the Theoretical Manual, the User's Manual, and the Programmer's Manual.

The Theoretical Manual is a commentary on the program. It is, first of all, intended to be an introduction to NASTRAN for all interested persons, including those who will use the program and those whose interests are less direct. For this purpose, the structure and the problem-solving capabilities of the program are described in a narrative style. The manual's most important function, however, is to justify the analytical and numerical procedures that underlie the program by presenting explanations and derivations of sufficient depth to be convincing.

The selection of material has not been an easy task because not everyone has the same concept of what the word "theory" means when it is applied to a computer program. A broad view concerning the selection of materials has been adopted; i. e., the formulation that will be solved, the development of the procedures or algorithms that will be used in the solution, the organization of the program, and the flow of data through the computer.

The User's Manual contains all of the information needed to solve problems with NASTRAN. It includes instruction in structural modeling techniques, instruction in input preparation, and information to assist the interpretation of output. It contains descriptions of all input data cards, restart procedures, and diagnostic messages.

The Programmer's Manual contains the information that is required for maintenance and modification of the program. It contains a complete description of the program code including the mathematical equations that are implemented in the Functional Models and describes the Executive System and the coding practices that have been employed.

The NASTRAN program is currently operational on the IBM 7094/7040, the IBM 360 models 50 through 95, the CDC 6400, 6500, and 6600, and the Univac 1108 Exec II computer systems. The plotters that can be utilized with these systems are the Stromberg Carlson 4020, the Benson Lehner LTE or STE, the Electronics Associates EIA 3500, the Display Data DD80, and the Calcomp 763.

Now that the initial development phase has been completed, there will be continuing maintenance by a NASTRAN Management Center at a yet undetermined NASA Center. The Office of Advanced Research and Technology will fund the maintenance and development tasks. In other words, the program will not become stagnant or die. In fact, the first year's improvements have been determined and priorities have been assigned. A few examples are:

1. Substructure Partitioning
2. Finite Element Thermal Analyzer
3. Dummy Element
4. Single Precision Option
5. Training Films

NASTRAN is the perfect tool to be used in the development of the shuttle vehicle. It will, first of all, do the job and do it efficiently; it will allow the monitoring NASA Centers, the prime contractors, the subcontractors, and other interested parties to exchange information freely and to converse in a common language; and possibly of equal importance, with the correct management and guidelines, it can save untold development time and costs.